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A database for quarkonium and open heavy-flavour production in hadronic collisions with HepData

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Abstract

We report on the creation of a database for quarkonium and open heavy-flavour production in hadronic collisions. This database, made as a collaboration between HepData and the ReteQuarkonii network of the integrating activity I3HP2 of the 7th Framework Programme, provides an up-to-date review on quarkonia and open heavy-flavour existing data. We first present the physics motivation for this project,

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which is connected to the aim of the ReteQuarkonii network, studies of open heavy-flavour hadrons and quarkonia in nucleus-nucleus collisions. Then we give a general overview of the database and describe the HepData database for particle physics, which is the framework of the quarkonia database. Finally we describe the functionalities of the database with as example the comparison of the production cross section for the J/ψ meson at different energies.

1 Motivation for a Database on quarkonium and open heavy-flavour physics

Quarkonia are bound states of $Q\bar{Q}$ pairs, where Q is a heavy quark, either a charm quark (c) or a beauty quark (b). The first quarkonium state discovered was the J/ψ particle ($c\bar{c}$) [1,2]. The quarkonium production mechanism is far from being understood and various models such as the Colour Singlet, nonrelativistic QCD approach (NRQCD) and the Colour Evaporation Model aim to explain how a heavy resonance state can be produced in hard processes, see [3] and references therein.

The study of quarkonia is fundamental for the understanding of the quark-gluon plasma (QGP), a deconfined state of matter produced in ultra-relativistic heavy-ion collisions. In 1986 Matsui and Satz predicted an anomalous suppression of the J/ψ particle in QGP produced in central heavy-ion collisions [4]. A normal suppression is observed in heavy-ion collisions without QGP formation due to the presence of nuclear matter (cold nuclear matter effects). If a QGP is formed, due to colour screening in the hot medium, the J/ψ should be dissociated (hot nuclear matter effects). In addition to this suppression mechanism, theoretical predictions based on recombination models account for an enhancement of J/ψ production due to regeneration in the medium [5,6] or at the phase space boundary [7–10]. Heavier states are also of great interest and their binding energies being different, their dissociation temperature should be different too. Theoretical approaches predict a sequential dissociation of quarkonium states, depending on the temperature of the produced medium [11].

In addition to the study of bound states, open heavy-flavour production (D and B mesons) can also probe hot nuclear matter. Heavy quarks, being produced at initial stage of the collision via hard scattering, interact with the formed QGP. The study of heavy-quark energy loss into the medium gives information on the nature and properties of the QGP (path length, density). Based on QCD, radiative energy loss of quarks should be lower than that of gluons due to the dead cone effect (reduction of in-medium heavy quark energy loss) [12–15]. This effect can be balanced by other mechanisms such as collisional energy loss [16, 17], in-medium fragmentation, recombination, coalescence [18–20] and initial state effects [21, 22].

More details on the production mechanism of heavy-flavour bound states, open heavy-flavours, and their interaction with nuclear medium, either cold or hot can be found in [3, 8, 23–35]. These effects are extensively studied at the LHC.

For the study of quarkonium and heavy-flavour production in heavy-ion and proton-proton collisions one needs to measure and compare spectra at different energies and from different colliding systems. To disentangle the anomalous from the normal suppression, it is necessary to compare observables in AA collisions with results from pp collisions and pA collisions at the same center of mass energy.

It is then necessary to have a complete overview of all existing data. This is the motivation for the creation of a database that contains all published results on quarkonia and open heavy-flavours in hadronic collisions. The need for the creation of such a database was pointed out by members of the ReteQuarkonii Network [36], itself focused on heavy-ion physics. In addition, quarkonia and open heavy-flavours are studied for other physics goals in particle physics and therefore all existing data from hadronic collisions need to be included in the database. This work is done in collaboration with HepData, the Durham high energy physics (HEP) Database Project. Quarkonia related references are included in the database and a dedicated webpage has been created as a review of quarkonium physics where all data are directly accessible [37].

2 Overview of the Database

When dealing with data and databases, the most challenging questions are related to the longevity of the data storage, their accessibility over time and their easy access via the web. This is why this project was done in collaboration with HepData, a well established database in HEP [38]. In this section, we briefly present HepData and its role in the quarkonia database. Then we present the Quarkonium Review Webpage.

2.1 HepData

HepData's "reaction database" is a repository of data from mainly particle physics with some content from nuclear physics. It has been hosted at Durham university since the 1970s with its content based on published data. Data records are stored by publication with data from approximately 8000 archived papers. More details can be found in [39, 40]. HepData has recently implemented a new software framework based on modern database and programming language technologies, as well as quality tools for the web interface [41].

Figure 1 shows a screenshot of the HepData webpage that is accessible via [38]. On the left hand-side the query form is blank. Users can search using

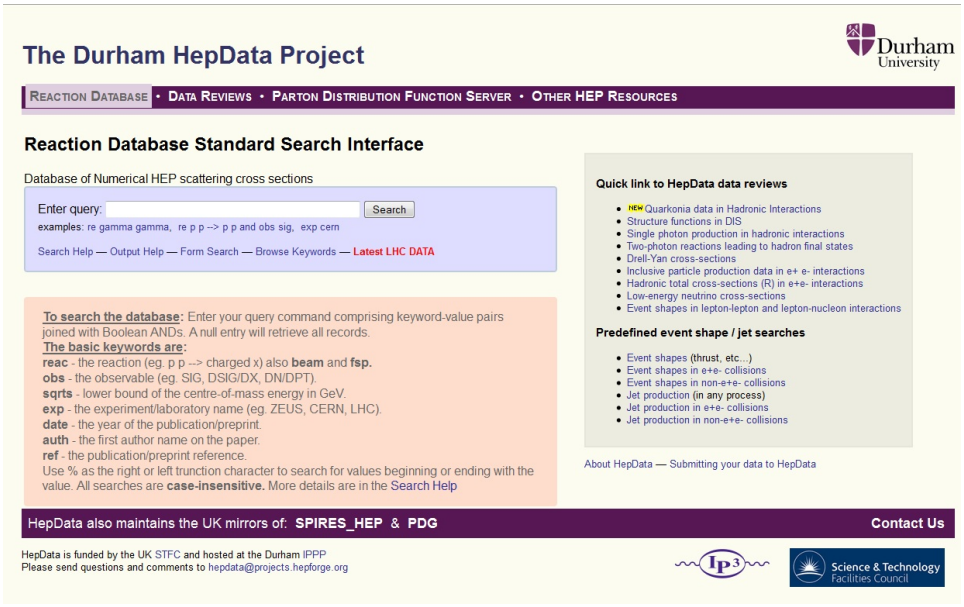

Figure 1: Screenshot of the HepData main webpage [38].

keywords, such as "FSP=J/PSI" to retrieve the records (188 publications at present) with a J/ψ in the final state. The results of this search is shown in Fig. 2, where only the first four records out of 188 are visible on the screenshot. This also illustrates that latest LHC data are included in HepData.

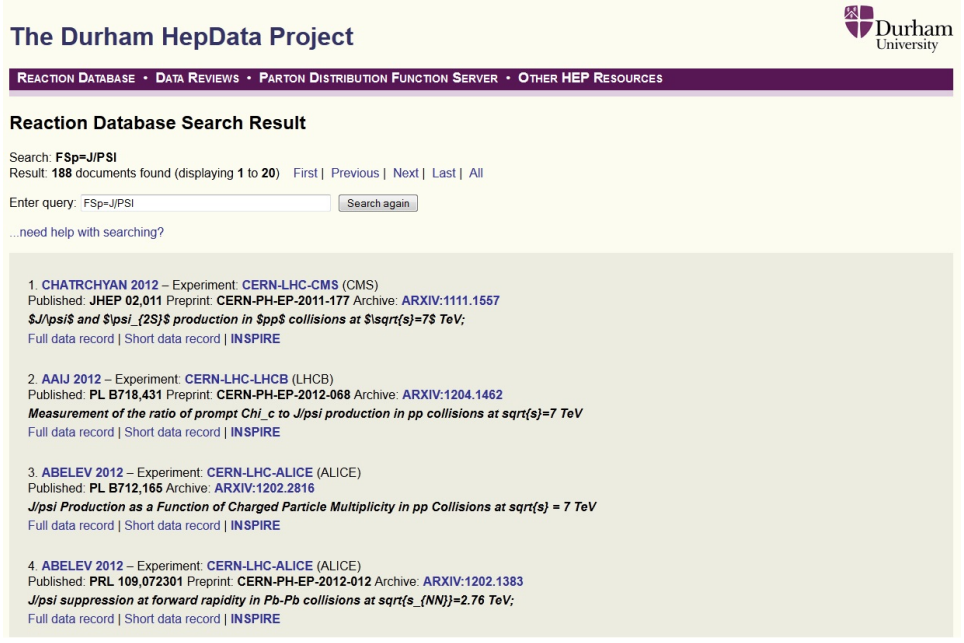

Figure 2: Screenshot of research of records with a J/ψ in the final state.

All the data discussed in this document are included in the traditional HepData database and therefore are accessible via direct search with the query form. On the right-hand side of Fig. 1 one can see 9 links to data reviews, focused on a specific subject. The Quarkonium Review Webpage is the latest one and will be discussed in the next section.

2.2 Quarkonium Review Webpage

HepData offers the possibility to create reviews on dedicated subjects and thus the Quarkonium Review Webpage was created to present all related results in a clear overview. This review contains 185 references at present, and is being updated with new results from the LHC and other experiments. Even though the physics motivation initially came from heavy-ion physics, the database contains data from all experiments which studied quarkonia and open heavy-flavours in hadronic collisions, including data from particle physics experiments. In total, 6 facilities and 25 experiments are considered. Figure 3 shows a screenshot of the Quarkonium Review Webpage, which is accessible on the HepData webpage or directly via [37].

On the web page, data are first grouped by accelerator facilities and experiments ("data from a specific experiment", link in red in Fig. 3). This includes data from the following nuclear and particle physics experiments:

- CERN-SPS (61 references), fixed-target experiments with beam energies from 120 GeV to 450 GeV: NA3 [42–46], NA10 [47–50], NA11 [51, 52], NA16 [53–56], NA27 [57–64], NA32 [65–71], NA34-3 [72], NA38 [73–83], NA50 [84–99], NA51 [100], NA60 [101, 102];
- FERMILAB (14 references), fixed-target experiments with beam energies of 800 GeV: E772 [103–106], E789 [107–112], E866 [113–116];
- HERA (12 references), fixed-target experiments with beam energies of 920 GeV: HERA-b [117–128];
- BNL-RHIC (20 references), collider experiments with $\sqrt{s} = 200$ GeV: PHENIX [129–144] , STAR [145–148];
- CERN SP$\bar{\text{P}}$S (7 references), collider experiments with $\sqrt{s} = 540 - 630$ GeV: UA1 [149–154], UA6 [155];
- Fermilab-Tevatron (33 references), collider experiments with $\sqrt{s} = 1.8 - 1.96$ TeV: CDF [156–179], D0 [180–188];
- CERN-LHC (38 references), collider experiments with $\sqrt{s} = 2.76 - 7$ TeV: ALICE, ATLAS, CMS, LHCb [189–196], ATLAS [197–204], CMS [205–217], LHCb [218–226].

Next, in order to make easier the search of a specific results, data are sorted out by initial state ("data for a specific initial state", link in red in Fig. 3):

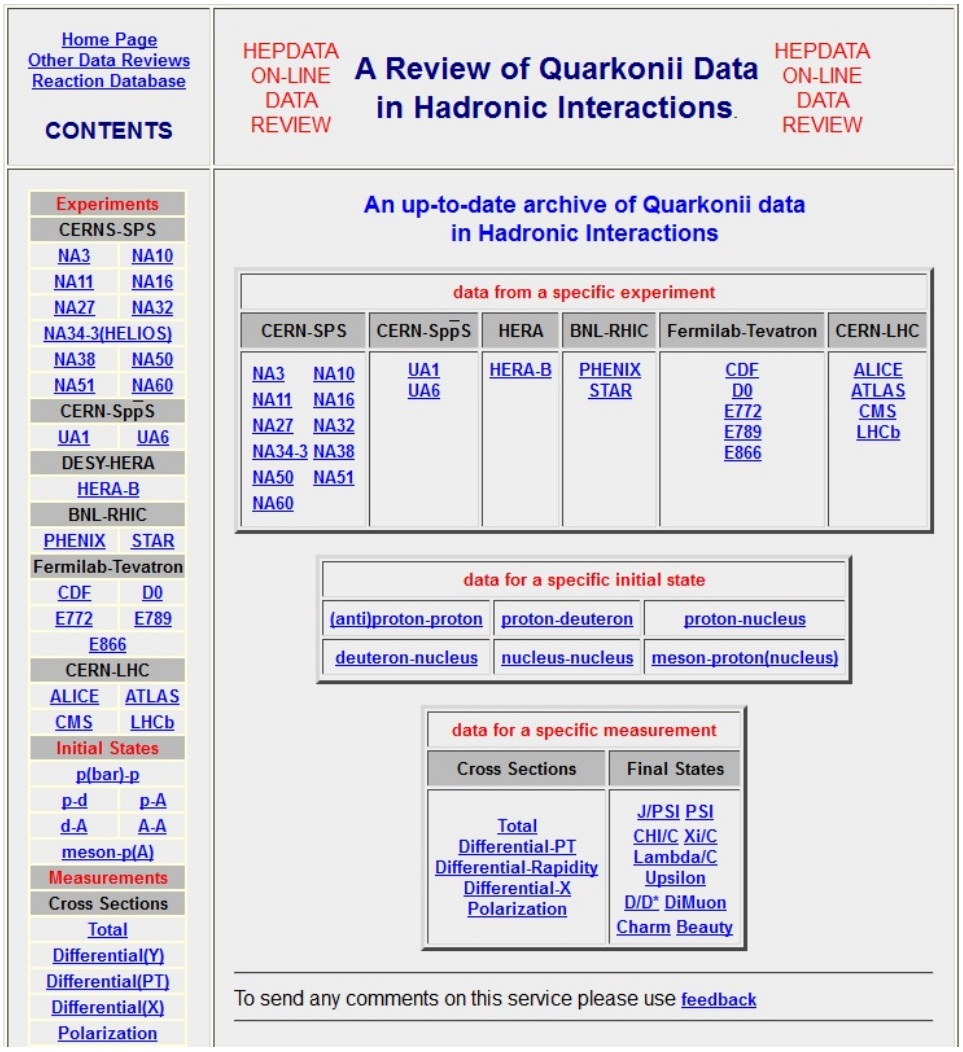

Figure 3: Screenshot of Quarkonium Review Webpage [37].

- proton-(anti)proton, proton-deuteron, deuteron-deuteron;
- proton-nucleus;
- deuteron-nucleus and nucleus-nucleus;
- meson-nucleus.

Finally, data are sorted out according to specific measurements and observables ("data for a specific measurement", link in red in Fig. 3):

- integrated cross sections, differential cross sections versus p_{T}, rapidity and x;
- polarization;

and by final states particles:

- J/ψ, ψ, χ(c) and Υ;
- D, D*, di-muon, charm and beauty.

When selecting data in a specific search, as for example J/ψ in Fig. 3, all related papers are listed, as shown in Fig. 4. In blue, there is a link to inSPIRE [227] where a PDF version of the publication can usually be obtained. The "[R]" link points to the full HepData record where all available plots in the paper can be found and the traditional HepData machinery can be used to visualize data tables and plot figures. This aspect will be discussed in the next section.

3 Use of the database

To quickly and easily compare data sets, one can use the graphical HepData tool available online. For each column of a data table the link "select plot" allows the user to select several data tables to be displayed in the same plot. Each data set is referenced by a number. Numbers are set in order of selection (the number one is attributed to first table). Graphics can then be customized. The advanced graphic interface (see Fig. 5) is user friendly with predefined fields where the user can easily select options and features such as:

- the size and aspect of the plot can be changed (Xsize,Ysize);
- axes can be set linear or logarithmic (Xscale, Yscale);
- axes range can be fixed by filling the xmin, xmax, ymin, ymax boxes;
- axes can be re-labeled (X-label, Y-label);

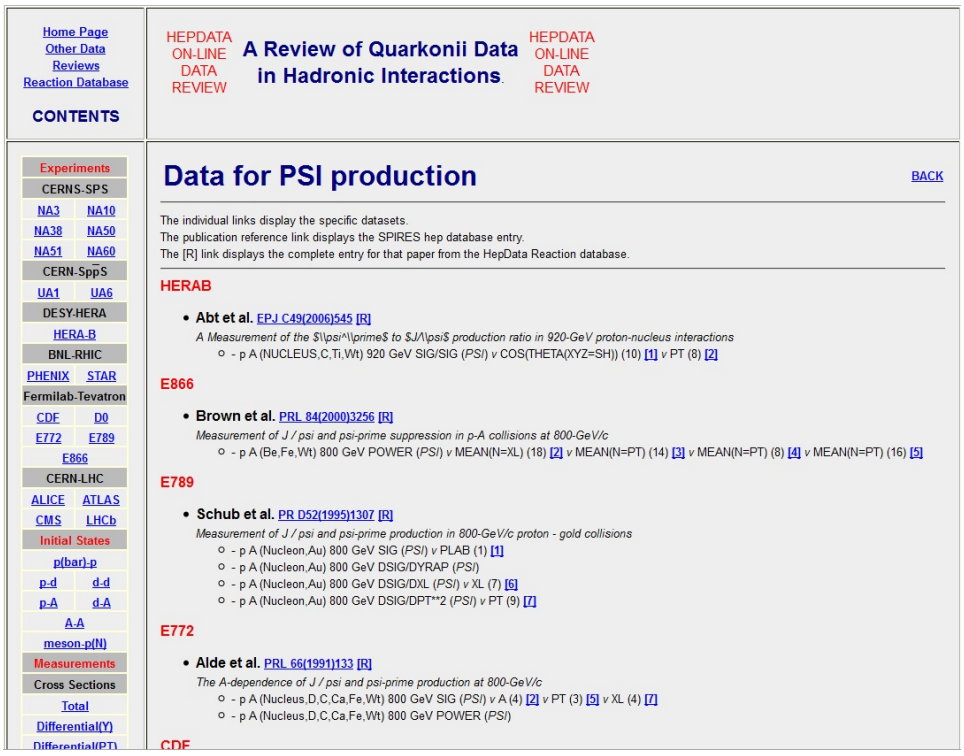

Figure 4: Screenshot of Quarkonium Review Webpage for the production of a J/ψ particle in the final state.

- a text box allows the addition of a title or comments to the plot (Text);
- the position of the labels and text can be adjusted (Xsize, Ysize);
- a factor can be applied to a data set with the scale command, for example "scale=5" ("5" is the factor to be applied to all data points in that particular set). This command is essential to compare data sets provided with different units, for example one in nanobarn and the other in microbarn (Option(n) for data set n);
- colour and icon type can be modified with the use of colour name and shape in the relevant option box (black, pink, cyan, green, square, diamond, triangle, filled, etc) (Option(n) for data set n). All commands in the option boxes are comma separated.

All data comparisons presented in this section were made online using the HepData graphical tool. Thus, they all can be easily reproduced by anyone. The HepData community is continuously working to improve the graphical tool.

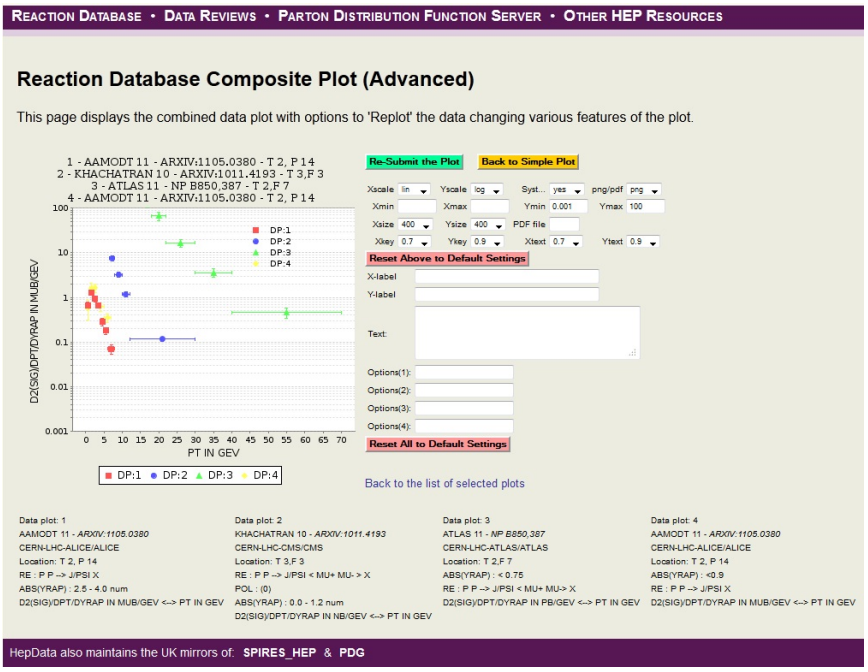

Figure 5: Screenshot of the advanced graphic plotting option from the HepData plotting tool.

Various comparison plots can be made to illustrate sample data records in the quarkonia database. Here we will focus on J/ψ production in pp collisions at energies from RHIC to LHC. Figure 6 shows, on the left plot, results in the central rapidity region. STAR data are obtained with e^+e^- pairs, in the region $|\eta| < 0.5$ (red squares,1) and PHENIX data with e^+e^-

pairs in $|y| < 0.35$ (blue circles, 2 and green triangles, 3). Only statistical uncertainties are shown, systematic uncertainties are available in data tables. One can see a good agreement between the two PHENIX measurements and the STAR one, in complementary p_{T} ranges. On the right plot, PHENIX results with $\mu^+\mu^-$ pairs in the region $-2.2 < |y| < -1.2$ are added (black circles, 4 and light blue circles, 5).

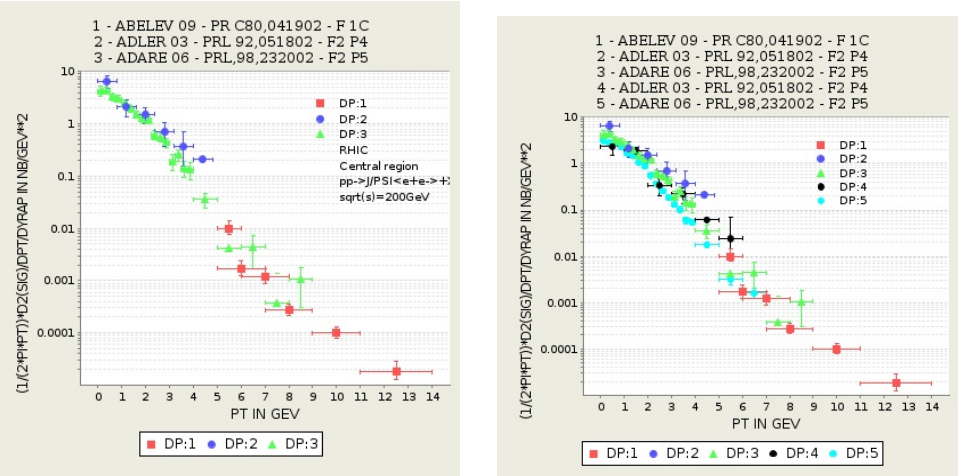

Figure 6: J/ψ p_{T} spectra at RHIC energies ($\sqrt{s} = 200$ GeV). Left: central rapidity region. Right: central and forward rapidity regions.

Figure 7 shows a similar comparison for results from UA1, CDF and D0. 1 (red squares) are UA1 results at $\sqrt{s} = 630$ GeV. Labels 2, 3, 5 (blue circles, green triangles and light blue circles) are CDF results at $\sqrt{s} = 1.8{-}1.96$ TeV. Labels 4, 6 (black circles and pink circles) are D0 at $\sqrt{s} = 1.8 - 1.96$ TeV. Also here, only statistical uncertainties are shown, systematic uncertainties are available in the data table. In this plot, one can see the p_{T} spectrum of the J/ψ production becoming harder with increasing energies.

Figure 8 displays p_{T} distributions of J/ψ produced in pp collisions at $\sqrt{s} = 7$ TeV, at mid-rapidity (ALICE, CMS and ATLAS) and forward rapidity (ALICE and LHCb). The right plot was published by the ALICE collaboration [189]. On the left, the same plot was reproduced with the HepData graphical tool with statistical uncertainties only. LHCb data are missing since they deal with direct J/ψ production and not inclusive production.

This exercise shows the possibility of using the Quarkonium Review Webpage with HepData graphical tools, to plot selected data sets. This tool is very useful to have a first quick comparison of data results from different experiments.

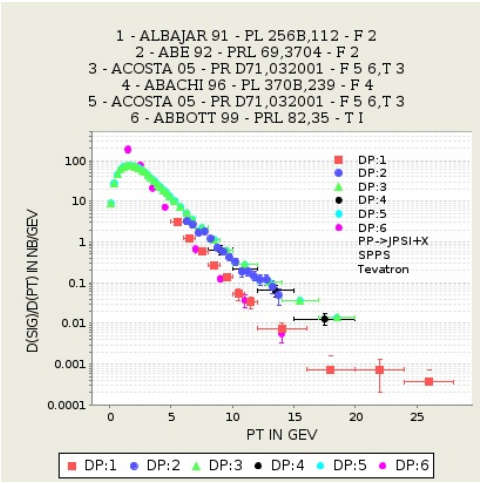

Figure 7: J/ψ p_{T} spectra in p$\bar{\mathrm{p}}$ collisions at SP$\bar{\mathrm{P}}$S energies ($\sqrt{s} = 630$ GeV) with UA1 experiment and at Tevatron energies ($\sqrt{s} = 1.8 - 1.96$ TeV) by CDF and D0 experiments.

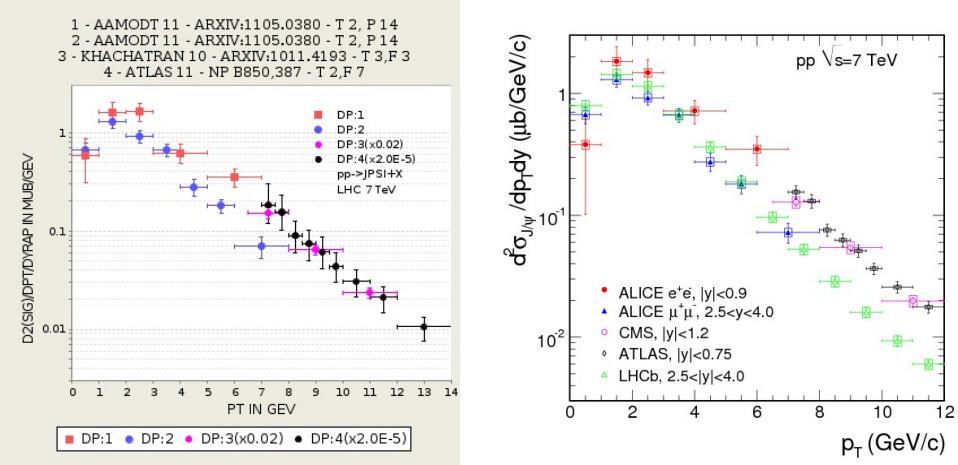

Figure 8: J/ψ p_{T} spectra in pp collisions at $\sqrt{s} = 7$ TeV at mid-rapidity (ALICE, CMS and ATLAS) and forward rapidity (ALICE and LHCb). Left: plot from HepData. Right: plot from ALICE publication [189].

4 Conclusion

We have reported on the creation of a database dedicated to quarkonia and open heavy-flavour physics in hadronic collisions. The need for this work was highlighted by the ReteQuarkonii network members and has been done in collaboration with the Durham HepData project whose "reaction database" provides the framework for the quarkonium and open heavy-flavour review webpage. We have included data from 25 experiments in this review from SPS to LHC energies and we have demonstrated the possibility of performing quick data comparison online with the HepData graphical tool. HepData is

continuously updated with new data and the Quarkonium Review Webpage will also include the new results. We encourage the use of this database and to report anomalies to us[3]. An extension of this database could be foreseen with the inclusion of data from electron colliders.

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